SHOCK CONDITION FORENSICS AND CRYPTIC PHASE TRANSFORMATIONS FROM CRYSTALLOGRAPHIC ORIENTATION RELATIONSHIPS IN ZIRCON

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In this study, we present an approach to constrain impact conditions that involves detailed analysis of the orientation relationships in shocked zircon ($ZrSiO_4$) to fingerprint histories of phase transformations and deformation processes, which can then be linked to phase diagrams to constrain pressure and temperature conditions during impact events.

At high-pressure conditions, zircon can undergo multiple transformations, including mechanical twinning [1, 2, 3, 4], conversion to the high-pressure polymorph reidite [2, 6, 7, 8], dissociation to ZrO_2 polymorphs and SiO_2, and formation of a granular texture [9, 10, 11], all of which are indicative of impact-related metamorphism. All of these phase transformations occur via specific, predictable crystallographic orientation relationships [2, 3, 7, 8, 12, 13]. Examples of four transformations are discussed below: twinning, reidite, dissociation, and recrystallization.

Electron backscatter diffraction mapping and orientation analysis of zircon grains from the Vredefort dome shows that twinning occurs as {112} lamellae and results in a disorientation of 65° / <110> [1, 2, 3]. Analysis of reidite-bearing zircon grains from a Ries suevite breccia clast shows that the zircon-to-reidite transformation can occur along irrational lamellae planes or form new grains (neoblasts) up to a few micrometres across [14]. The transformation to reidite results in the alignment of one $\{112\}_{reidite}$ with $\{100\}_{zircon}$, and alignment of another $\{112\}_{reidite}$ with $\{112\}_{zircon}$ [14]. Zircon grains from Mistastin Lake impact glass preserve coronas of twinned monoclinic ZrO_2 (baddeleyite) grain networks with interstitial silicate glass likely only related to thermal dissociation, but not high shock pressures [15]. Orientation analysis of the baddeleyite reveals discrete domains of up to twelve systematically-related orientations with planar boundaries. The baddeleyite orientations in each domain are consistent with known relationships from a two-stage transformation from a single cubic ZrO_2 parent (via three tetragonal ZrO_2 variants where $\langle 100\rangle_{tetZrO2}$ align with $\langle 100\rangle_{cubicZrO2}$) [16]. The cubic ZrO_2 crystallites have a systematic epitaxial relationship with the zircon host, whereby only one of the $\langle 100\rangle_{cubicZrO2}$ is aligned with either $\langle 100\rangle_{zircon}$, $\langle 110\rangle_{zircon}$, or $\langle 101\rangle_{zircon}$. Analysis of granular zircon from the Acraman impact structure [17] shows that zircon has recrystallised in up to three dominant orientations that have 90° / <110> disorientation relationships. This relationship can be explained by nucleation of zircon granules from (a) zircon in the initial host orientation, and (b) a reversion from reidite, now no longer present in the sample. Given the tetragonal symmetry of both phases, reversion from reidite can result in up to three dominant orientation variants: one cluster with similar orientation to the parent zircon; and two clusters with an approximate 90° / <110> disorientation from the initial host zircon. This relationship cannot be explained via reversion to zircon from ZrO_2 polymorphs or from twinned zircon, which would predict other orientation relationships.

We present new pressure-temperature diagrams for the Zr-Si-O system showing phase relationships under extreme conditions, compiled using available empirical and theoretical constraints, which have been combined with the above findings from microstructural analysis of zircon to constrain conditions during impact events. This study demonstrates how measurement of crystallographic orientations can be combined with known orientation relationships of transformations can be used to develop ‘orientation heritage’ and infer the former presence of phases that, in turn, can be used as evidence to infer impact conditions that are generally cryptic due to recrystallization.

[1] Moser et al., 2011 *Can J Earth Sci*; [2] Timms et al., 2012 *Met & Plan Sci*; [3] Erickson et al., 2013a *Am Min*; [4] Erickson et al., 2013b *GCA*; [5] Leroux et al., 1999 *GCA*; [6] Glass et al., 2002 *Am Min*; [7] Cavosie et al., 2015 *Geology*; [8] Reddy et al., 2015 *Geology*; [9] Bohor et al., 1993 *EPSL*; [10] Wittmann et al., 2006 *Met & Plan Sci*; [11] Tohver et al., 2012 *GCA*; [12] Kaiser et al., 2008 *J Eur Ceram Soc*; [12] Smith and Newkirk, 1965 *Acta Cryst*; [13] Bansal and Heuer, 1972 *Acta Met*; [14] Erickson et al., in review *CMP*; [15] Zanetti et al. 2014 *Met Soc Abs*; [16] Cayron et al., 2010 *J Am Ceram Soc.* [17] Schmieder et al., 2015, *GCA.*